Initial Assumptions & Constants

$$V_{ru} := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{bmatrix} 100000 \ m^3$$

Upper Reservoir Volume

$$V_{rl} := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{bmatrix} 100000 \ m^3$$

Lower Reservoir Volume

$g := 9.81 \ \frac{m}{s^2}$ Acceleration Due to Gravity

$\mu := 8.9 \cdot 10^{-4} \ Pa \cdot s$ Fluid Viscosity

$\rho := 1000 \ \frac{kg}{m^3}$ Fluid Density

$t_g := 6 \ hr$ Time to Empty Reservoir

$t_p := 8 \ hr$ Time to Fill Reservoir

$\eta_t := 0.9$ Efficiency of Turbine

$\eta_p := 0.9$ Efficiency of Pump

$A := 0.9$ Plant Availability

$\Delta h := \begin{bmatrix} 300 & 450 & 600 & 750 \end{bmatrix}^{\mathrm{T}} \ m$

Elevation Difference

$\phi := 20 \ °$ Bedding angle of mine seam

$$L := \left(\left(300 \ m + \left(\frac{\Delta h - 300 \ m}{\sin(\phi)} \right) \right) \cdot 1.1 \right) \qquad L = \begin{bmatrix} 330 \\ 812 \\ 1295 \\ 1777 \end{bmatrix} m$$

Pipe Length

$$D_p := \begin{bmatrix} 1.5 \\ 2.1 \\ 2.6 \\ 3 \\ 3.35 \end{bmatrix} m$$

Pipe Diameter

$$A_s := \pi \cdot \frac{{D_p}^2}{4}$$

Pipe Cross Sectional Area

$$A_s = \begin{bmatrix} 1.767 \\ 3.464 \\ 5.309 \\ 7.069 \\ 8.814 \end{bmatrix} m^2$$

$\varepsilon_p := 0.25\ mm$

Pipe Surface Roughness

$$\frac{\varepsilon_p}{D_p} = \begin{bmatrix} 1.667 \cdot 10^{-4} \\ 1.19 \cdot 10^{-4} \\ 9.615 \cdot 10^{-5} \\ 8.333 \cdot 10^{-5} \\ 7.463 \cdot 10^{-5} \end{bmatrix}$$

Pipe Relative Roughness

Fluid Dynamics Calculations

$$m_g := \frac{V_{ru}}{t_g \cdot 3600 \; \frac{s}{hr}}$$

Volume Flow Rate (Generating)

$$m_g = \begin{bmatrix} 4.63 \\ 9.259 \\ 13.889 \\ 18.519 \\ 23.148 \end{bmatrix} \frac{m^3}{s}$$

$$m_p := \frac{V_{rl}}{t_p \cdot 3600 \; \frac{s}{hr}}$$

Volume Flow Rate (Pumping)

$$m_p = \begin{bmatrix} 3.472 \\ 6.944 \\ 10.417 \\ 13.889 \\ 17.361 \end{bmatrix} \frac{m^3}{s}$$

$$V_g := \frac{m_g}{A_s}$$

Average Fluid Velocity (Generating)

$$V_g = \begin{bmatrix} 2.62 \\ 2.673 \\ 2.616 \\ 2.62 \\ 2.626 \end{bmatrix} \frac{m}{s}$$

$$V_p := \frac{m_p}{A_s}$$

Average Fluid Velocity (Pumping)

$$V_p = \begin{bmatrix} 1.965 \\ 2.005 \\ 1.962 \\ 1.965 \\ 1.97 \end{bmatrix} \frac{m}{s}$$

$i := 0 \,..\, 4$

$$Re_{g_i} := \frac{\rho \cdot V_{g_i} \cdot D_{p_i}}{\mu}$$

Reynolds Number (Generating)

$$Re_g = \begin{bmatrix} 4.415 \cdot 10^6 \\ 6.308 \cdot 10^6 \\ 7.642 \cdot 10^6 \\ 8.831 \cdot 10^6 \\ 9.885 \cdot 10^6 \end{bmatrix}$$

$$Re_{p_i} := \frac{\rho \cdot V_{p_i} \cdot D_{p_i}}{\mu}$$

Reynolds Number (Pumping)

$$Re_p = \begin{bmatrix} 3.312 \cdot 10^6 \\ 4.731 \cdot 10^6 \\ 5.732 \cdot 10^6 \\ 6.623 \cdot 10^6 \\ 7.414 \cdot 10^6 \end{bmatrix}$$

Приближения

$$f := 1$$

Ограничения

$$\frac{1}{\sqrt{f}} \mathbf{=} -2 \cdot log\left(\frac{\varepsilon_p \cdot D_p^{\,-1}}{3.7} + \frac{2.51}{x \cdot \sqrt{f}}\right)$$

Решатель

$$ff\left(x, D_p\right) := \mathbf{find}\left(f\right)$$

Friction Factors According to Colebrook Equation

$$j := 0 \,..\, 3$$

$$h_{g_{i,j}} := ff\left(Re_{g_i}, D_{p_i}\right) \cdot \frac{L_j \cdot V_{g_i}^{\,2}}{2\ D_{p_i} \cdot g}$$

Head Loss (Generating)

$$h_g = \begin{bmatrix} 1.04 & 2.56 & 4.08 & 5.6 \\ 0.724 & 1.781 & 2.839 & 3.897 \\ 0.537 & 1.323 & 2.109 & 2.894 \\ 0.455 & 1.119 & 1.784 & 2.449 \\ 0.401 & 0.987 & 1.573 & 2.159 \end{bmatrix} \boldsymbol{m}$$

$$h_{p_{i,j}} := ff\left(Re_{p_i}, D_{p_i}\right) \cdot \frac{L_j \cdot V_{p_i}^{\,2}}{2\ D_{p_i} \cdot g}$$

Head Gain (Pumping)

$$h_p = \begin{bmatrix} 0.589 & 1.449 & 2.31 & 3.17 \\ 0.41 & 1.008 & 1.607 & 2.206 \\ 0.304 & 0.749 & 1.194 & 1.638 \\ 0.257 & 0.634 & 1.01 & 1.386 \\ 0.227 & 0.559 & 0.89 & 1.222 \end{bmatrix} \boldsymbol{m}$$

$$H_{g_{i,j}} := \Delta h_j - h_{g_{i,j}}$$

Effective Head (Generating)

$$H_g = \begin{bmatrix} 298.96 & 447.44 & 595.92 & 744.4 \\ 299.276 & 448.219 & 597.161 & 746.103 \\ 299.463 & 448.677 & 597.891 & 747.106 \\ 299.545 & 448.881 & 598.216 & 747.551 \\ 299.599 & 449.013 & 598.427 & 747.841 \end{bmatrix} \boldsymbol{m}$$

$H_{p_{i,j}} := \Delta h_j + h_{p_{i,j}}$ Effective Head (Pumping)

$$H_p = \begin{bmatrix} 300.589 & 451.449 & 602.31 & 753.17 \\ 300.41 & 451.008 & 601.607 & 752.206 \\ 300.304 & 450.749 & 601.194 & 751.638 \\ 300.257 & 450.634 & 601.01 & 751.386 \\ 300.227 & 450.559 & 600.89 & 751.222 \end{bmatrix} \mathbf{m}$$

$P_{t_{i,j}} := \rho \cdot g \cdot H_{g_{i,j}} \cdot m_{g_i} \cdot \eta_t$ Turbine Power (Generating)

$$P_t = \begin{bmatrix} 12.22 & 18.289 & 24.358 & 30.427 \\ 24.466 & 36.642 & 48.818 & 60.994 \\ 36.722 & 55.019 & 73.316 & 91.614 \\ 48.976 & 73.392 & 97.808 & 122.225 \\ 61.231 & 91.767 & 122.304 & 152.84 \end{bmatrix} \mathbf{MW}$$

$$P_{p_{i,j}} := \frac{\rho \cdot g \cdot H_{p_{i,j}} \cdot m_{p_i}}{\eta_p}$$

Pump Power (Pumping)

$$P_p = \begin{bmatrix} 11.376 & 17.086 & 22.796 & 28.505 \\ 22.739 & 34.139 & 45.538 & 56.938 \\ 34.097 & 51.179 & 68.261 & 85.342 \\ 45.456 & 68.221 & 90.986 & 113.752 \\ 56.814 & 85.262 & 113.71 & 142.158 \end{bmatrix} \mathbf{MW}$$

$$\eta_{rt_{i,j}} := \frac{P_{t_{i,j}} \cdot t_g}{P_{p_{i,j}} \cdot t_p}$$

Round Trip Efficiency

$$\eta_{rt} = \begin{bmatrix} 80.56\% & 80.28\% & 80.14\% & 80.06\% \\ 80.69\% & 80.5\% & 80.4\% & 80.34\% \\ 80.77\% & 80.63\% & 80.56\% & 80.51\% \\ 80.81\% & 80.68\% & 80.62\% & 80.59\% \\ 80.83\% & 80.72\% & 80.67\% & 80.64\% \end{bmatrix}$$

$hr_g := 365 \cdot A \cdot t_g$ Maximum Annual Running Hours (Generating) $hr_g = 1971\ \mathbf{hr}$

$hr_p := 365 \cdot A \cdot t_p$ Maximum Annual Running Hours (Pumping) $hr_p = 2628\ \mathbf{hr}$

Electricity Price Calculations

$Elec_{sell} := 80 \, \frac{\text{¤}}{MW \cdot hr}$ Average Price at which Electricity is Sold (Generating)

$Elec_{buy} := 30 \, \frac{\text{¤}}{MW \cdot hr}$ Average Price at which Electricity is Bought (Pumping)

$C_p := 0.9$ Plant Capacity Factor

$$R_{elec} := \left(Elec_{sell} \cdot hr_g \cdot P_t - Elec_{buy} \cdot hr_p \cdot P_p\right) \cdot C_p \qquad R_{elec} = \begin{bmatrix} 926937 & 1383083 & 1839230 & 2295376 \\ 1858505 & 2777568 & 3696631 & 4615693 \\ 2791846 & 4176416 & 5560986 & 6945556 \\ 3724883 & 5574517 & 7424151 & 9273784 \\ 4658075 & 6972999 & 9287922 & 11602845 \end{bmatrix} \text{¤}$$

Annual Revenue From Electricity Sales

Civil Works Calculations

$Vol_{shaft\_ex} := \frac{(3.5\ m)^2 \cdot \pi}{4} \cdot 326\ m$ $\qquad Vol_{shaft\_ex} = 3136\ m^3$

Volume of Existing Shaft

$Vol_{shaft\_new_i} := A_{s_i} \cdot L_i$ Volume of Excavations For New Shaft $Vol_{shaft\_new} = ?\ m^3$

You have 5 values of As and 4 values of L. Presumably you want to calculate 20 volumes? Use matrix multiplicaqtion to do this. That is, muliply column vector A by the transpose of column vector L.

$Vol_{shaft\_new} := A_s \cdot L^{\mathrm{T}}$

$$Vol_{shaft\_new} = \begin{bmatrix} 583.158 & 1.436 \cdot 10^3 & 2.288 \cdot 10^3 & 3.141 \cdot 10^3 \\ 1.143 \cdot 10^3 & 2.814 \cdot 10^3 & 4.485 \cdot 10^3 & 6.156 \cdot 10^3 \\ 1.752 \cdot 10^3 & 4.313 \cdot 10^3 & 6.875 \cdot 10^3 & 9.436 \cdot 10^3 \\ 2.333 \cdot 10^3 & 5.743 \cdot 10^3 & 9.153 \cdot 10^3 & 1.256 \cdot 10^4 \\ 2.909 \cdot 10^3 & 7.161 \cdot 10^3 & 1.141 \cdot 10^4 & 1.567 \cdot 10^4 \end{bmatrix} m^3$$

$P_{shaft} := 5\ \frac{¤}{m^3}$ Cost of Shaft Excavations per m3

$C_{shaft} := P_{shaft} \cdot Vol_{shaft\_new}$ Capital Cost of Shaft Excavations

$$C_{shaft} = \begin{bmatrix} 2916 & 7178 & 11441 & 15704 \\ 5715 & 14070 & 22424 & 30779 \\ 8760 & 21567 & 34374 & 47181 \\ 11663 & 28714 & 45764 & 62814 \\ 14543 & 35804 & 57065 & 78326 \end{bmatrix} ¤$$

$P_{res} := 5\ \frac{¤}{m^3}$ Cost of Reservoir Excavations per m3

$GH_l := 100\ m$ Generator Hall Length
$GH_w := 20\ m$ Generator Hall Width
$GH_h := 40\ m$ Generator Hall Height
$Vol_{gh} := GH_l \cdot GH_w \cdot GH_h$ Generator Hall Volume $Vol_{gh} = (8 \cdot 10^4)\ m^3$

$C_{gh} := P_{res} \cdot Vol_{gh}$ Capital Cost of Generator Hall Excavations $C_{gh} = 400000\ ¤$

$Vol_{res\_ex} := 10000\ m^3$ Volume of Existing Reservoirs

$Vol_{res\_new} := V_{ru} + V_{rl} - Vol_{res\_ex}$ Volume of Excavations For Reservoirs

$$Vol_{res\_new} = \begin{bmatrix} 190000 \\ 390000 \\ 590000 \\ 790000 \\ 990000 \end{bmatrix} m^3$$

$C_{res} := P_{res} \cdot Vol_{res\_new}$ Capital Cost of Reservoir Excavations

$$C_{res} = \begin{bmatrix} 950000 \\ 1950000 \\ 2950000 \\ 3950000 \\ 4950000 \end{bmatrix} ¤$$

$C_{ex} := C_{shaft} + C_{gh} + C_{res}$ Total Capital Cost of Excavations $C_{ex} = ?$

$C_{civil} := C_{ex} \cdot 1.5$ Total Civil Costs $C_{civil} = ?$

$$C_t := 10000\ \frac{¤}{MW} \cdot P_t$$

Total Turbine Costs

$$C_t = \begin{bmatrix} 122200 & 182891 & 243582 & 304273 \\ 244659 & 366419 & 488179 & 609939 \\ 367216 & 550190 & 733164 & 916138 \\ 489757 & 733920 & 978083 & 1222246 \\ 612306 & 917671 & 1223035 & 1528400 \end{bmatrix} ¤$$

$C_{bop} := 0.2 \cdot C_t$

Total Balance of Plant Costs

$$C_{bop} = \begin{bmatrix} 24440 & 36578 & 48716 & 60855 \\ 48932 & 73284 & 97636 & 121988 \\ 73443 & 110038 & 146633 & 183228 \\ 97951 & 146784 & 195617 & 244449 \\ 122461 & 183534 & 244607 & 305680 \end{bmatrix} ¤$$

$R_g := 0\ ¤$ Total Grants & Subsidies at Start of Project

$$ACP := 10\,\frac{\text{¤}}{MW} \cdot P_t$$

Annual Capacity Payment

$$ACP = \begin{bmatrix} 122 & 183 & 244 & 304 \\ 245 & 366 & 488 & 610 \\ 367 & 550 & 733 & 916 \\ 490 & 734 & 978 & 1222 \\ 612 & 918 & 1223 & 1528 \end{bmatrix} \text{¤}$$

$\alpha := 0.03$ Annual Rate of Inflation

$i := 0.05$ Annual Rate of Interest

$\beta := 0.01$ Annual Electricity Price Escalation Rate

$K := 25$ Years Until Major Plant Replacement

$N := 50$ Lifetime of Project

$$\delta := \frac{1+\alpha}{1+i} \qquad \delta = 0.981 \qquad \varepsilon := \frac{1+\beta}{1+i} \qquad \varepsilon = 0.962$$

$$PU_{semo} := 107 \; \frac{¤}{MW} \qquad PMW_{semo} := 0.686 \; \frac{¤}{MW \cdot hr}$$

$$AC_{semo} := 2788 \; ¤ + PU_{semo} \cdot P_t + 413 \; ¤ + PMW_{semo} \cdot P_t \cdot hr_g \cdot C_p$$

Annual Costs Charged by SEMO

$$AC_{semo} = \begin{bmatrix} 19379 & 27414 & 35449 & 43484 \\ 35591 & 51711 & 67831 & 83951 \\ 51817 & 76040 & 100264 & 124488 \\ 68040 & 100364 & 132689 & 165014 \\ 84264 & 124691 & 165118 & 205545 \end{bmatrix} ¤$$

$C_{semo} := 1115$ ¤

Upfront Costs Charged by SEMO

$PVF_{mp} := \delta^{K}$

Present Value Factor of Major Plant Replacement

$PVF_{mp} = 0.618$

$F_t := 0.5$

Factor of Turbine Cost Incurred on Major Replacement

$C_{mp} := C_t \cdot F_t$

Capital Cost of Major Plant Replacement

$$C_{mp} = \begin{bmatrix} 61100 & 91446 & 121791 & 152137 \\ 122329 & 183209 & 244090 & 304970 \\ 183608 & 275095 & 366582 & 458069 \\ 244878 & 366960 & 489041 & 611123 \\ 306153 & 458835 & 611518 & 764200 \end{bmatrix}$$ ¤

$PV_{mp} := C_{mp} \cdot PVF_{mp}$

Present Value of Major Plant Replacement

$$PV_{mp} = \begin{bmatrix} 37778 & 56541 & 75303 & 94066 \\ 75636 & 113278 & 150920 & 188562 \\ 113525 & 170091 & 226657 & 283223 \\ 151408 & 226891 & 302374 & 377856 \\ 189294 & 283697 & 378100 & 472504 \end{bmatrix}$$ ¤

$C_{cap} := \left(C_{civil} + C_t + C_{bop} + C_{semo}\right) - R_g$ $\qquad C_{cap} = ?$

Capital Cost

$$C_{cap} := \frac{i \cdot (1+i)^{N}}{(1+i)^{N} - 1} \cdot C_{cap}$$

Annual Cost of Capital

$$AC_{o\&m} := 36000 \, \frac{\text{¤}}{MW} \cdot P_t$$

Annual Operation & Maintenance Cost

$$AC_{o\&m} = \begin{bmatrix} 439920 & 658408 & 876896 & 1095384 \\ 880771 & 1319108 & 1757445 & 2195782 \\ 1321978 & 1980684 & 2639391 & 3298098 \\ 1763124 & 2642111 & 3521098 & 4400086 \\ 2204301 & 3303614 & 4402927 & 5502241 \end{bmatrix} \text{¤}$$

$$R_{totalelec} := \varepsilon \cdot \frac{\left(1 - \varepsilon^{N}\right)}{(1 - \varepsilon)} \cdot R_{elec}$$

Lifetime Value of Electricity Revenue

$$AC_t := \left(AC_{o\&m} + AC_{semo}\right) \cdot \frac{\left(\delta - \delta^{(N+1)}\right)}{(1 - \delta)}$$

Present Value of Annual Costs

$$AC_{cap} = ?$$

$$NPV := -\left(C_{cap} + AC_t + PV_{mp}\right) + R_{totalelec}$$

$$NPV = ?$$

$$AC_t = \begin{bmatrix} 14611177 & 21817309 & 29023441 & 36229572 \\ 29151223 & 43608364 & 58065505 & 72522646 \\ 43703022 & 65428354 & 87153686 & 108879018 \\ 58252808 & 87243388 & 116233968 & 145224549 \\ 72803618 & 109060943 & 145318269 & 181575595 \end{bmatrix} \text{¤}$$

$$R_{totalelec} = \begin{bmatrix} 20048443 & 29914291 & 39780139 & 49645987 \\ 40197048 & 60075172 & 79953295 & 99831419 \\ 60383987 & 90330426 & 120276865 & 150223305 \\ 80564365 & 120569528 & 160574691 & 200579854 \\ 100748085 & 150816857 & 200885630 & 250954402 \end{bmatrix} \text{¤}$$